# Does fox control improve red–legged partridge (*Alectoris rufa*) survival? An experimental study in Northern Spain

A. Mateo–Moriones, R. Villafuerte & P. Ferreras

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**Abstract**

*Does fox control improve red–legged partridge (*Alectoris rufa*) survival? An experimental study in Northern Spain.*— This work evaluates the effectiveness of fox control as a method to improve the survival of red–legged partridge (*Alectoris rufa*). We radio–tracked 89 adult partridges and their chicks (62 few days old chicks and 46 over one–month–old chicks) and monitored their nests (N = 45) on two hunting estates in northern Spain over two years. Generalist predators (red fox, *Vulpes vulpes*, and magpie, *Pica pica*) were selectively controlled on one half of each estate during the first year, and on the other half in the second year. We estimated the effect of predator control on survival rates. Predator control did not improve survival rates for adult partridges and nests, but it improved chick survival, especially for chicks over one–month old.

Key words: Predator control, Radio–tracking, Red–legged partridge, Red fox, Survival rates.

**Resumen**

*¿Puede el control de zorros mejorar la supervivencia de la perdiz roja (*Alectoris rufa*)? Un estudio experimental en el Norte de España.*— Evaluamos la efectividad del control selectivo de zorros como método para mejorar la supervivencia de la perdiz roja (*Alectoris rufa*). Para ello, radio–seguimos 89 perdices adultas y sus pollos (62 pollos de pocos días y 46 pollos de más de un mes de edad), e hicimos un seguimiento de sus nidos en dos cotos de caza del Norte de España durante dos años. En la mitad de la superficie de cada coto se controlaron de forma selectiva los depredadores generalistas (zorro, *Vulpes vulpes*, y urracas, *Pica pica*) durante el primer año, y los tratamientos se invirtieron entre zonas durante el segundo año. Estimamos el efecto del control de depredadores sobre las tasas de supervivencia. El control de depredadores no mejoró la supervivencia de los adultos y nidos de perdiz, pero sí mejoró la supervivencia de los pollos, especialmente para los pollos de más de un mes de edad.

Palabras clave: Control de depredadores, Radio–seguimiento, Perdiz roja, Zorro común, Tasas de supervivencia.

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*Ainhoa Mateo–Moriones, Rafael Villafuerte & Pablo Ferreras, Inst. de Investigación en Recursos Cinegéticos (IREC, CSIC–UCLM–JCCM), Ronda de Toledo s/n., 13071, Ciudad Real, España (Spain).*

Corresponding author: Ainhoa Mateo–Moriones, E–mail: ainhoamm@yahoo.es

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## Introduction

The red–legged partridge (*Alectoris rufa*) is a galliform species distributed in southwestern Europe (Iberian Peninsula, France, Italy) and the UK. It is globally considered as 'vulnerable' (Aebischer & Potts, 1994) and as a 'species of special interest' at the European level (Tucker & Heath, 1994). During recent decades, red–legged partridge populations have declined notably (Cramp & Simmons, 1980; Aebischer & Potts, 1994; Blanco–Aguiar et al., 2003). The causes of decline in Spain are multiple, including habitat loss (Buenestado et al., 2008), pathogens (Millán et al., 2001; Villanúa et al., 2008; Díaz–Sanchez et al., 2011) and genetic introgression resulting from restocking with farm–reared partridges (Negro et al., 2001; Barilani et al., 2007; Blanco–Aguiar et al., 2008), excessive hunting pressure (Blanco–Aguiar et al., 2003) and predation (Moleón et al., 2008; Buenestado et al., 2009).

Control of predator species can reduce predation suffered by game species and facilitate their recovery (Tapper et al., 1996; Smith et al., 2010). However poorly designed predator control could be counterproductive, since it could induce high densities of small predators by a process of mesopredator release (Crooks & Soulé, 1999; Blanco–Aguiar et al., 2001; Beja et al., 2009). An indiscriminate or unselective predator control may also affect other species and lead to an imbalance of natural ecosystems (Coté & Sutherland, 1997).

Despite these concerns predator control is a widespread game management practice in Spain (Delibes–Mateos et al., 2009); its effectiveness on improving the demographic parameters of small game species is still unknown. In the case of the red–legged partridge, a few studies have focused on the effect of predator control on nest survival (Yanes et al., 1998; Herranz, 2000), but studies of the effect on survival of adult and chick survival are lacking.

Our aim was to evaluate the effectiveness of predator control as a tool to improve the survival of several age classes of the red–legged partridge. We evaluated the effect of predator control on the survival of adults, nests and partridge chicks during a two–year experimental study on two hunting estates in Northern Spain.

Table 1. Main landscape characteristics: habitat surface in hectares (ha) and % in parentheses.

*Tabla 1. Principales características del paisaje: superficie en hectáreas (ha) y % entre paréntesis.*

| Landscape characteristics | Study Area 1 | Study Area 2 |
|---|---|---|
| Surface covered (ha) | | |
| | 5,518.7 | 7,111.0 |
| Mediterranean scrubland/forest (%) | | |
| | 1,050.4 (19%) | 1,868.5 (26.3%) |
| Irrigated croplands (%) | | |
| | 22.9 (0.4%) | 161.6 (2.3%) |
| Unirrigated croplands (%) | | |
| | 4,387.0 (79.5%) | 5,013.0 (70.5%) |
| Total arable croplands (%) | | |
| | 4,409.9 (79.9%) | 5,174.6 (72.8%) |
| Unproductive land/fallow | | |
| | 58.4 (1.1%) | 67.8 (1.0%) |
| Diversity index (Shannon *H*) | | |
| | 0.248 | 0.316 |
| Average patch size (ha) | | |
| | 17.7 | 23.16 |

## Material and methods

### Study areas

This study was carried out over two consecutive years (2008 and 2009) on two hunting estates in the southwestern part of Navarra, Northern Spain: Arroniz (Study Area 1: 5,477 ha) and Sesma (Study Area 2: 7,067 ha), both with similar environmental and social characteristics. Most of the land area of these estates is covered by arable crops (> 70%), with natural vegetation consisting of Mediterranean scrubland with some pine plantations (See table 1 for further information). The main game species are red–legged partridges, European rabbits (*Oryctolagus cuniculus*) and Iberian hares (*Lepus granatensis*). Both study areas have medium abundances of red–legged partridge (spring Kilometer Abundance Index, KAI, number of individuals recorded per kilometre travelled: 1.5). Both study areas are extensive game estates (low to medium hunters density), where partridges are hunted by walk–up shooting with dogs. Game management is carried out by one gamekeeper in each estate and consists of water supply, and some areas of reserve/refuges where hunting is not practised. Farm–bred partridges were not released during the study period and no artificial feeding was provided. The most important predators for the red–legged partridge vary in abundance; red foxes (*Vulpes vulpes*) are in high abundance (summer KAI 0.14–0.22 in Study Area 1 and 0.25–0.28 in Study Area 2) and magpies (*Pica pica*) are in low abundance (spring KAI 0.06 in Study Area 1 and 0.16 in Study Area 2). Other potential partridge predators include diurnal raptor species, such as Montagu's harrier (*Circus pygargus*), hen harrier (*Circus cyaneus*), marsh harrier (*Circus aeruginosus*), golden eagle (*Aquila chrysaetos*) and booted eagle (*Hieraaetus pennatus*), and nocturnal raptors such as eagle owl (*Bubo bubo*) and short–eared owl (*Asio flammeus*).

Each study area was divided into two treatment zones: a predator control zone (hereafter PC) and non–predator control zone (hereafter NPC). During the first year of the study (2008), the gamekeepers from each hunting estate selectively and intensively controlled red foxes in the PC zone, while no predator control was applied in the NPC zone. Treatments were reversed between zones during the second year of the study (2009). Predator control was performed from February to December by authorized staff (gamekeepers and some hunters from the hunting societies) only, using legal methods. During the hunting season, hunters were also authorised to shoot red foxes during their hunting activity.

We planned to control magpies at the beginning of the study as they are considered one of the main predators of red–legged partridge nests and chicks (Yanes et al., 1998). A total of 86 magpies were culled during the study (60 in 2008 and 26 in 2009; table 2). However, the background magpie abundance in these areas is very low (maximum KAI recorded values: 0.06 in Study Area 1 and 0.16 in Study Area 2 in autumn 2008), making it difficult to assess the effect of controlling the abundance of this species.

### Monitoring predator populations

Fox populations were monitored using spotlight counts, performed once a month, from spring (March–April) to autumn (October). Magpie populations were monitored by diurnal counts, carried out twice a year (April and October). In both cases, KAIs were calculated.

### Capture and radio–tracking of adult and chick partridges and location of nests

From February to the end of April, adult partridges were captured in all study areas, using two methods: (i) cages with a living decoy (Casas et al., 2009) and (ii) night captures using a net and a spotlight (Buenestado et al., 2009; Casas et al., 2009).

Adult partridges were radio–tagged with a collar transmitter model TW–3 (11 g of weight, Biotrack Ltd, Dorset, UK) and radio–tracked every 24–48 hours, either until the transmitter batteries ran out (at around eight months) or at the end of the annual tracking period (November). The radio–tracking of adult partridges allowed us to locate their nests during the breeding season. Nests were geo–referenced and monitored from a distance using binoculars to scan the nest location, trying not to disturb the hen during the incubation period. Hatching dates were recorded if the nest succeeded, and cause and date of failure were noted if the nest was unsuccessful. Once hatched, chicks were captured at two different ages: (i) chicks between one and four days old (Chicks_1) and (ii) chicks over a month of life (Chicks_2). Those chicks captured earlier (Chicks_1) were radio–tagged with small radio–transmitters (model PIP21, 0.45 g weight, Biotrack Ltd., Dorset, UK) glued to their back (Mateo–Moriones et al., 2012) and located daily. Chicks_2 were radio–tagged with transmitters (model TW–41, 4.5 g. weight, Biotrack, Ltd., Dorset, UK) placed dorsally as a backpack (Mateo–Moriones et al., 2012) and located every 1–3 days. According to tests both in captivity and in the field, these tagging methods seem to have reduced effects on chicks' survival (Mateo–Moriones et al., 2012). Radio–tracking of partridges (adults and chicks) and monitoring of nests provided the data required for estimating survival rates and cause of mortality of adult partridges, nests and chicks.

Table 2. Number of foxes (Fx) and magpies (Mg) harvested during each study year in the predator control zones of Study Area 1 and 2: *Game managers in Study Area 1 decided not to control magpies in 2009 due to their low abundance in the control zone that year.

*Tabla 2. Número de zorros (Fx) y urracas (Mg) extraídos durante cada año en las zonas de control de depredadores del área de estudio 1 y 2: *Durante 2009 los gestores del área de estudio 1 decidieron no realizar control de urracas debido a su baja abundancia en la zona de control de depredadores correspondiente a ese año.*

| | 2008 | | 2009 | |
|---|---|---|---|---|
| Study Area | Fx | Mg | Fx | Mg |
| 1 | 30 | 32 | 34 | 0* |
| 2 | 40 | 28 | 39 | 26 |
| Total | 70 | 60 | 73 | 26 |

### Estimation of survival rates of adult partridges, nests and chicks

Survival rates were estimated for each age group by using the most appropriate application in program MARK 4.0, based on the available data (White & Burnham, 1999; Rotella et al., 2004). MARK provides estimates of survival rates and allows the comparison of different models with combinations of factors or variables to the observed survival data. The models are ranked according to their explanatory ability using the Akaike Information Criterion (AIC, White & Burnham, 1999).

Adult survival was estimated with the 'Known Fate' application; candidate factors included in the models were the time of year (1. Winter coveys; 2. Mating; 3. Nesting; and 4. Broods), year (2008/2009), study area (1 and 2), treatment effects (PC. Predator control/ NPC. Non–predator control), sex (male/female), and age class (subadult/adult).

Nest success was estimated with the 'Nest Survival' application, with model candidate factors: year, study area, treatment, sex of the adult incubating the nests (both males and females can incubate, Casas et al., 2009) and laying period (early/late, before, or after the median laying date).

The survival of the chicks during the first two weeks of life (Chicks_1) was estimated with the 'Nest Survival' application (Moynahan et al., 2007), including as factors: year, study area, treatment, age and brood identity (in order to control for non–independence of

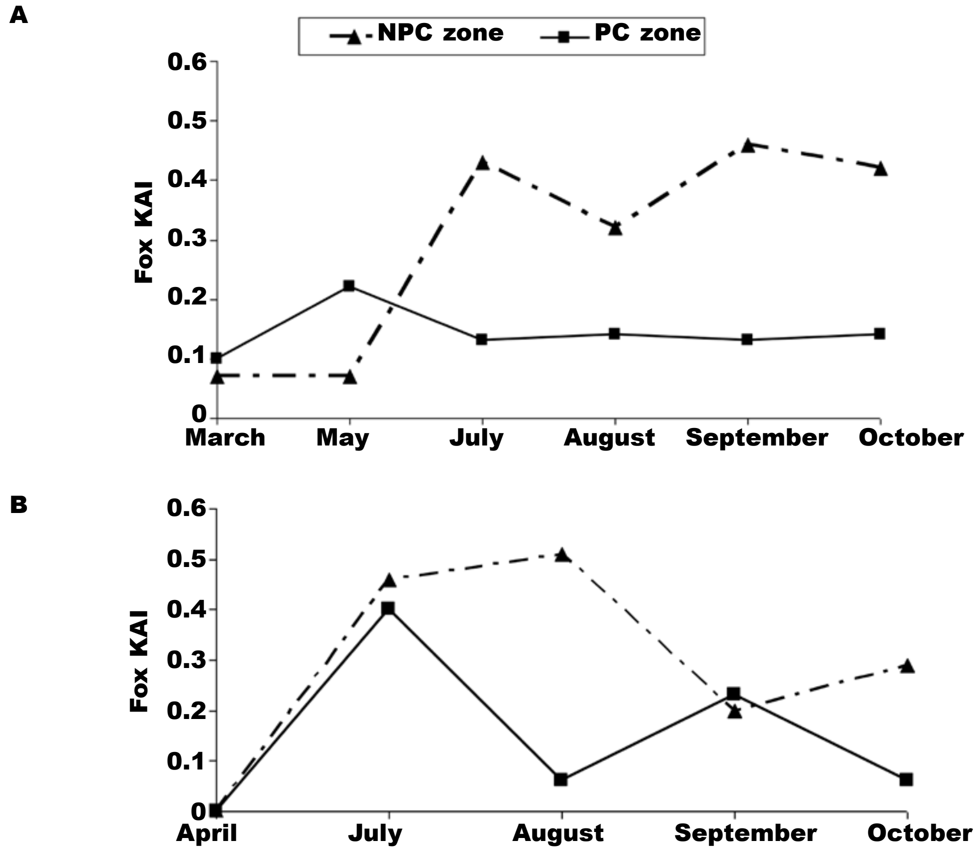


Fig. 1. Fox Kilometric Abundance Indexes (KAI) in the zones where predator control was applied (PC zone, continuous line with squares) and in the zones where it was not applied (NPC zone, discontinuous line with triangles) during 2009, in Study Area 1 (A) and Study Area 2 (B).

*Fig. 1. Índices kilométricos de abundancia de zorros (KAI) en zonas donde se aplicó control de depredadores (zona PC, línea continua con cuadrados) y en zonas donde no se aplicó (zona NPC, línea discontinua con triángulos) durante el año 2009 en el área de estudio 1 (A) y el área de estudio 2 (B).*

survival of sibling chicks). For chicks over 1 month of life (Chicks_2) we used the 'Known Fate' application (Cooch & White, 2010), with the following factors in the models: year, study area, treatment and weight of the chicks at capture (as a correlate of their age).

In each case, models were ranked according to the value of the AIC corrected for small samples (AICc). Those models with a ΔAIC < 2 with respect to the lowest AIC were considered as the most plausible models for explaining the observed data. Our main goal was to determine whether the model including the treatment (predator control) was included among the most plausible models. This would indicate that predator control affects the survival rate being considered in the model. Moreover, the overall weight of treatment as a factor explaining the survival rates was calculated considering the partial weights of all the models including such factor. We also estimated the survival rates of adult partridges, nests and chicks for each treatment.

There was some uncertainty concerning the fate of some of the chicks, as we lost the signal of some transmitters during the radio–tracking period. In order to take into account such uncertainty we considered two extreme scenarios: (i) the minimum survival scenario that assumes that all signal losses were due to the death of the chicks, and (ii) the maximum survival scenario that assumes that all the signal losses were due to transmitter failure or early exhaustion of batteries, not implying the chick death. We assumed that true survival rates would be included between the values estimated for such scenarios.

## Results

We independently assessed the effect of predator control on five different parameters: (1) predator abundance; (2) survival of adult partridges; (3) nests success; (4) survival of Chicks_1; and (5) survival of Chicks_2.

Table 3. Ranking of models resulting from the survival analysis with Program MARK for adult partridges. The model including the treatment (predator control) is underlined.: MLh. Model Lekelihood; Np. Number parameter; D. Deviance.

*Tabla 3. Ordenación de los modelos resultantes del análisis de supervivencia con el Programa MARK para perdices adultas. El modelo que incluye el tratamiento (control de depredadores) aparece subrayado: MLh. Modelo de probabilidad; Np. Número de parámetro; D. Desviación.*

| Model | AICc | ΔAICc | AICc weights | MLh | Np | D |
|---|---|---|---|---|---|---|
| S4 Periods | 259.515 | 0 | 0.213 | 1 | 4 | 251.448 |
| S4 Periods+Age | 260.111 | 0.596 | 0.158 | 0.742 | 5 | 250.009 |
| S4 Periods+Year | 260.429 | 0.914 | 0.134 | 0.633 | 5 | 250.327 |
| S4 Periods+Study Area | 261.528 | 2.013 | 0.077 | 0.365 | 5 | 252.426 |
| S4 Periods+Treatment | 261.545 | 2.030 | 0.077 | 0.362 | 5 | 251.443 |
| S4 Periods+Sex | 261.546 | 2.031 | 0.077 | 0.362 | 5 | 251.444 |
| Constant Survival | 262.655 | 3.139 | 0.044 | 0.208 | 1 | 260.648 |

### Effects of predator control on predator abundance

During the study, 143 foxes were harvested in the control zones (70 in 2008; 73 in 2009; table 2). During 2009, fox control had a clear effect on fox abundance, mainly in Study Area 1, where the KAI clearly decreased later in the year. In autumn, the fox KAI value was around 0.22 in the zones where control was applied, while it was 0.46 in zones without control (fig. 1A). In Study Area 2, although the effects were not so evident, the fox KAI in the NPC zone was almost always above the value of the KAI index in the PC zone (fig. 1B). In 2008, the low number of spotlight counts prevented a similar analysis. Even so, the only spotlight carried out, in August 2008, showed that fox abundance was lower in PC zones (fox KAI 0.19) than in NPC zones (fox KAI 0.26).

### Effect of predator control on survival of adult partridges

Eighty–nine adult partridges were captured and radio–tagged during this study (52 in PC zones; 37 in NPC zones). Overall, 44% of the partridges were alive at the end of the tracking period in the PC zones, compared to 54% in the NPC zones. Predation was the main identified cause of death (68.2% of total deaths of radio–tagged animals, which represent 33.7% of the total number of radio–tagged partridges).

Most adult predation (73%) occurred between April and June (30% in April; 30% in May and 13% in June). Predations caused by raptors occurred in April (54%) and May (46%), while predation by carnivores occurred mostly in May (58.3%) and June (33.3%), during the nesting period. However, predation by carnivores continued to occur until the end of the tracking period, although in lower proportions.

The best model of adult survival included the time of year, and it was followed by the models that also included age, year and study area (table 3). Although the model including the treatment (control / non–control) is not among the most plausible models, it can not be completely ruled out (ΔAIC = 2.030; table 2). The treatment had a much lower relative weight (0.077) to explain survival of adult partridges than the time of year (0.736), age (0.158) or year (0.134).

### Effect of predator control on nest survival

We located 45 nests during the study (27 in PC zones; 18 in NPC zones). Thirty–three percent of the nests across all treatments had hatched at the end of the breeding season. Predation was identified as the main cause of nest loss in both study areas, accounting for 84% of all losses.

Medium–size carnivores (mainly foxes, but also dogs and badgers) were identified as the main nest predators (30% of total nest predations; 39% in PC zones and 18 % in NPC zones). Mustelids and small mammals (hedgehogs, rats) were secondary nests predators (26.7% of total nest predations; 22.2% in PC zones and 33.3% in NPC zones). Corvids predated 3.3% of the nests. Other identified causes of nest loss were predation of the hen by raptors (6.6%), agriculture and livestock (6.6%) and nest abandonment by the adult (10%). It was not possible to identify the cause of 20% of nest losses, since no egg remains or evidence was found around the nest. In these cases predation was assumed to be the cause of nest loss.

Four of the five models that best explained nest survival included the study area (table 4). The predator control treatment was included in the fifth ranked model, which also included the study area, with a ΔAIC of 1.927 (table 3). The model including only the study area explains nest survival better than the model which also included the treatment. However, no model was better (ΔAIC < 2) than the constant survival model.

Table 4. Ranking of models resulting from the survival analysis with Program MARK for partridge nests. The model including the treatment (predator control) is underlined. (For abbreviations see table 3.)

*Table 4. Ordenación de los modelos resultantes del análisis de supervivencia con el Programa MARK para los nidos de perdiz. El modelo que incluye el tratamiento (control de depredadores) aparece subrayado. (Para las abreviaturas ver tabla 3.)*

| Model | AICc | ΔAIC | AICc weights | MLh | Np | D |
|---|---|---|---|---|---|---|
| Study Area | 195.352 | 0 | 0.263 | 1 | 2 | 191.331 |
| Study Area+Sex | 195.791 | 0.439 | 0.211 | 0.802 | 3 | 189.750 |
| Study Area+Year | 196.600 | 1.248 | 0.141 | 0.535 | 3 | 190.559 |
| Constant Survival | 197.158 | 1.806 | 0.106 | 0.405 | 1 | 195.151 |
| Study Area+Treatment | 197.279 | 1.927 | 0.101 | 0.381 | 3 | 191.238 |
| Study Area+Period | 197.365 | 2.013 | 0.096 | 0.365 | 3 | 191.324 |
| Sex | 197.715 | 2.363 | 0.081 | 0.306 | 2 | 193.695 |

Among the factors considered, the relative weight of treatment (predator control) to explain nest success was much lower (0.101) than the study area (0.812), or the sex of the incubating parent (0.292).

## Effect of predator control on survival of Chicks_1

Sixty–two chicks between one and four days old (34 in PC zones; 28 in NPC zones) were captured and radio–tagged during the study. Overall, four chicks were radio–tracked until the transmitter battery went flat about 15 days after tagging (1 in PC zones and 3 in NPC zones), Eleven nests were undoubtedly predated (5 in PC zones and 6 in NPC zones). It was difficult to identify the nature of predation due to the small size of the chicks at this age: often, no remains or evidence other than the transmitter was werefound. The location of the transmitters and signs on it and on the surrounding vegetation revealed that at least three (27.3% of total predations in NPC zones) were predated by mustelids, two (18.2% of total in NPC zones) by foxes, and one (9.1%, in PC zones) by avian predators. We were not able to identify the predator in five cases (45.5%). Twenty–eight transmitters found showed no evidence of predation (21 in PC zones and 7 in NPC zones). Similar values of fallen tags were observed in previous tests in captivity (Mateo–Moriones et al., 2012). We lost the signal of 19 transmitters and, consequently, the final fate of those chicks was unknown. These chicks were considered in the two extreme scenarios previously mentioned (see Material and Methods).

The best models for small chick survival under the minimum survival scenario were the constant model, and those including the treatment (ΔAIC = 0.373), the year, the study area and the age of the chicks (table 5A). The constant model had a relative weight of 0.320, while the model with the treatment had a relative weight of 0.262 under the minimum survival scenario. The best models under the maximum survival scenario were those including the year and the constant model (table 5B). The model that included treatment was ranked in third place, with a ΔAIC = 2.043 (table 5B). Predator control treatment was the factor that best explained the survival of small chicks (relative weight: 0.168) in those factors included in the minimum survival scenario (year weight: 0.099) and the second best factor (0.105, after year, 0.292) under the maximum survival scenario.

Estimated daily survival for the chicks during their first two weeks of life was slightly higher in the zones with predator control (between 0.961 ± 0.017 under the minimum and 0.974 ± 0.015 under the maximum survival scenario) than in the zones without predator control (between 0.918 ± 0.029 and 0.988 ± 0.011, respectively).

## Effect of predator control on survival of Chicks_2

We captured and radio–tagged 46 one–month– old chicks during the study, 35 in PC zones and 11 in NPC zones. A total of 24 chicks survived until the end of the radio–tracking period (November), 19 (54%) in the PC zones and five (45%) in the NPC zones. At least three chicks (9%) were predated in the PC zones, and two (18%) in the NPC zones. The remaining tagged birds (37% in both zones) lost their transmitters or their signal was lost during the tracking period.

Under the minimum survival scenario, the model including the treatment as factor ranked best, above the constant model (ΔAIC = 1.461; table 6A), whereas under the maximum survival scenario, the model including the treatment ranked in second place after the constant model (ΔAIC = 0.491; table 6B). The predator control treatment was the factor that best explained the survival of large chicks both under the minimum survival (relative weight: 0.421) and under the maximum survival scenarios (relative weight: 0.178).

Weekly survival rates for chicks over one–month old was estimated to be between 0.951 ± 0.017 and 0.987 ± 0.009 (for minimum and maximum survival

Table 5. Ranking of models resulting from the survival analysis with Program MARK for partridge chicks in the first two weeks of life: A. Under the minimum survival scenario; B. Under the maximum survival scenario. The model including the treatment (predator control) is underlined. (For abbreviations see table 3.)

*Table 5. Ordenación de los modelos resultantes del análisis de supervivencia con el Programa MARK para pollos de perdiz durante las dos primeras semanas de vida: A. Bajo el escenario de mínima supervivencia; B. Bajo el escenario de máxima supervivencia. El modelo que incluye el tratamiento (control de depredadores) aparece subrayado. (Para las otras abreviaturas ver la tabla 3.)*

**A**

| Model | AICc | ΔAICc | AICc weights | MLh | Np | D |
|---|---|---|---|---|---|---|
| Constant survival | 89.964 | 0 | 0.203 | 1 | 1 | 87.945 |
| Treatment | 90.338 | 0.373 | 0.168 | 0.829 | 2 | 86.279 |
| Year | 91.396 | 1.432 | 0.099 | 0.488 | 2 | 87.338 |
| Study Area | 91.661 | 1.697 | 0.087 | 0.428 | 2 | 87.603 |
| Year | 91.728 | 1.764 | 0.084 | 0.414 | 2 | 87.670 |
| Time | 99.277 | 9.313 | 0.002 | 0.009 | 12 | 73.702 |

**B**

| Model | AICc | ΔAICc | AICc weights | MLh | Np | D |
|---|---|---|---|---|---|---|
| Year | 38.695 | 0 | 0.292 | 1 | 2 | 34.635 |
| Constant survival | 39.237 | 0.543 | 0.223 | 0.762 | 1 | 37.217 |
| Treatment | 40.737 | 2.043 | 0.105 | 0.360 | 2 | 36.678 |
| Study Area | 41.206 | 2.511 | 0.083 | 0.285 | 2 | 37.146 |
| Age | 41.253 | 2.558 | 0.002 | 0.278 | 2 | 37.193 |
| Brood | 47.892 | 9.19 | 0.000 | 0.010 | 10 | 26.752 |

scenarios, respectively) in the PC zones and between 0.867 ± 0.050 and 0.956 ± 0.031 in the NPC zones.

## Discussion

In the present work predation was identified as the main cause of mortality for adults, nests and chicks of the red–legged partridge. Therefore, it would be expected that measures aimed to reduce predator abundances should increase partridge survival. Nevertheless, according to our results, predator control had different effects on each age group . It did not improve the survival of adults and nests, while it had a positive effect on chick survival, more evident in larger chicks. The lack of a decrease in fox abundance on the predation control sites early in the year, i.e. when nesting takes place, may explain the lack of an ability to show higher survival both of adults and of nests on the predation control plots. Differences in fox abundances appeared later in the year, coinciding with the end of the small chicks period and with the larger chicks period.

Previous studies have reported improvements as high as 40% in nest success of red–legged partridges through intensive control of foxes, magpies, dogs and feral cats (Yanes et al., 1998; Herranz, 2000). However, our study did not show such an improvement in the nest success due to predator control. The lack of differences in fox abundances between zones during the nesting period could explain this lack of effect. This suggests that to obtain results in the breeding season, fox control should start before that season. However, a high number of nest predations was due to other non–controlled predators, particularly some small mammalian predators, such as mustelids, hedgehogs and rodents. Unfortunately, we lack information on the abundance of such predators during the study. Corvids are usually considered important nest predators but they had a very low effect on our nests. This is probably associated with their low abundance in our study areas.

In our study, predator control clearly improved survival rates for large chicks, under both scenarios considered. However, the survival of small chicks was only slightly improved by predator control despite predation being the most important cause of chick mortality. In a similar study conducted in south–central Norway, Steen & Haugvold (2009)

Table 6. Ranking of models resulting from the survival analysis with Program MARK for partridge chicks after the first month of life: A. Under the minimum survival scenario; B. Under the maximum survival scenario. The model including the treatment (predator control) is underlined. (For abbreviations see table 3.)

*Table 6. Ordenación de los modelos resultantes del análisis de supervivencia con el Programa MARK para pollos de perdiz tras el primer mes de vida: A. Bajo el escenario de mínima supervivencia; B. Bajo el escenario de máxima supervivencia. El modelo que incluye el tratamiento (control de depredadores) aparece subrayado. (Para las abreviaturas ver tabla 3.)*

**A**

| Model | AICc | ΔAICc | AICc weights | MLh | Np | D |
|---|---|---|---|---|---|---|
| Treatment | 103.428 | 0 | 0.421 | 1 | 2 | 99.371 |
| Constant survival | 104.889 | 1.461 | 0.203 | 0.482 | 1 | 102.871 |
| Weight | 104.952 | 1.524 | 0.196 | 0.467 | 2 | 100.894 |
| Year | 106.271 | 2.842 | 0.102 | 0.241 | 2 | 102.213 |
| Study Area | 106.818 | 3.389 | 0.077 | 0.183 | 2 | 102.760 |
| Time | 116.865 | 13.437 | 0 | 0 | 12 | 91.281 |

**B**

| Model | AICc | ΔAICc | AICc weights | MLh | Np | D |
|---|---|---|---|---|---|---|
| Constant survival | 41.435 | 0 | 0.228 | 1 | 1 | 39.415 |
| Treatment | 41.926 | 0.491 | 0.178 | 0.782 | 2 | 37.867 |
| Study srea | 41.993 | 0.557 | 0.172 | 0.756 | 2 | 37.934 |
| Weight | 42.246 | 0.811 | 0.152 | 0.666 | 2 | 38.187 |
| Year | 43.254 | 1.819 | 0.092 | 0.403 | 2 | 39.195 |
| Time | 57.217 | 15.782 | 0 | 0 | 12 | 31.592 |

reported that local, intensive predator control had no measurable effects on chick production or survival of willow ptarmigan (*Lagopus lagopus*) even when predation was identified as the main cause of death. They suggested that their control areas may have been relatively small, which could have allowed the immigration of predators from local areas. It is possible that a similar effect may have taken place in our study, particularly in Study Area 2, where the decreasing trend of fox abundance was not quite clear throughout the experiment. A non–well conducted predator control carried on by the gamekeeper in this hunting estate, maybe less intensive, or extending also into the *a priori* non–predator control area, could explain the differences in the decreasing trend of fox abundances between the two study areas, but we have no data to confirm that –Amundson & Arnold (2011) observed that fox removal had no positive effect on mallard (*Anas platyrhynchos*) duckling survival, but this could be related to the high abundance of mink, which was not controlled. Similarly, we observed high predation by small carnivores, but their control was not considered in our study as they are protected in Spain.

In a classical study in Southern England, predator control carried out on two hunting estates improved brood size and abundance of the grey partridge (*Perdix perdix*, Tapper et al., 1996). Several differences between our work and that of Tapper et al. (1996) might explain the different results obtained in our study. Tapper et al. (1996) carried out intensive predator control over three consecutive years in each area in the study compared to just one year in our study. The effect of predator control was probably accumulative over the years, an effect that was not possible in our study. Furthermore, more species of predator were controlled in the English study, such as corvid species rather than magpies and some small mustelids. These predators were not controlled in our study (most are protected species in Spain), but they e had important roles as predators in our study area, mainly for nests, as they were was the second cause of losses, and probably for small chicks, even when the effect in this age group e was not easy to test (Calderón, 1977). Finally, there are some ecological differences between the two study areas, mainly related to biodiversity and predator abundance. A high diversity of predators, including mammals, birds and reptiles occur in the Iberian peninsula, and over 30 of these include red–legged partridge in their diets (Calderón, 1977; Duarte et al., 2008). Control was applied only to two of the predator species in our study and this may not have been enough to reduce the effects of predation; it should be considered that the wide diversity of predator species in our study area includes several raptor species identified as partridge predators. Raptor predators are an important source of adult mortality, mainly during the mating period (Calderón, 1977; Buenestado et al., 2009).

In conclusion, predator control, carried out in our study as performed in most Spanish hunting estates, was not effective in improving survival of adult partridges and their nests, probably because it was not effective in reducing abundances over a short period of time. Future research using indirect measures based on habitat improvements (nesting habitat, food and refuge availability) during the nesting season may prove effective to reduce partridge mortalities. A nest habitat with adjacent vegetation cover during the first days of life, for example, may reduce the need for the chicks to walk long distances looking for food (mainly small arthropods), and thus decrease the risk of being predated. In addition to well–designed selective predator control campaigns  such as starting controls earlier, such measures could be effective to mitigate predation and improve survival of partridge populations.

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